Reviewing Constructivist Theories to Help Foster Creativity in Programming Education

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***Abstract*—In cognitive psychology, creativity is an established and well-researched construct. Creativity is linked to openness to experience, and creating innovative solutions. It is this synthesis of prior knowledge and experience that reflects the core ideas of constructivist learning theory. Recently, the investigation and measurement of students' creative capacities has gained traction in computing. Although being creative is important in the solution of programming problems, creativity is neither embedded in computing curricula as a learning objective, nor established in competency-based educational practice. Assuming that creativity is a malleable component of competency, the present paper aims at investigating constructivist theories to help foster creativity as part of programming competency in computing. Accordingly, learning theories from Piaget, Vygotskiy, Bruner and Dewey were reviewed with regard to their perspective on human learning and the creation of new knowledge through connections. Their review and alignment with the context of programming education results in recommendations for pedagogical interventions, such as collaborative project work, social interaction, scaffolding, active learning, multi-sensory experiences, gamification, and authentic tasks. As a next step, these pedagogical approaches will be investigated with regard to their effects on the creativity of novice learners of programming.**

***Index Terms*—higher education, programming, instructional methods, pedagogy, creativity, cognition, developmental theory**

I. Introduction

Several studies reveal that the arts and crafts can help STEM students improve their competencies [1]–[4]. Anecdotal evidence from Nobel Prize laureates, engineers and STEM professionals further indicate the role of creativity for performance. Steve Jobs, for example, once described creativity as factor for successful product design and provided a definition: "Creativity is just connecting things." [5] According to Jobs, creative people "were able to connect experiences they've had and synthesize new things. And the reason they were able to do that was that they've had more experiences or they have thought more about their experiences than other people." [5] The dictionary provides similar definitions of creativity as "the ability to create" [6] and "the ability to produce or use original and unusual ideas." [7]

In psychological theory, creativity is a well-established construct related to the personality dimension "openness to experience" [8], [9]. It is surprising though that the potential influence of creativity in the problem solving processes of programming is not yet established in curricular guidelines [10], [11]. This work in progress constitutes the starting point of research on pedagogical interventions fostering creativity among computing students learning to program. As the creation of new knowledge and solutions is inherent in constructivist learning, it is the goal to review the educational theory as a framework and identify instructional methods supporting creative problem solving.

II. Related Work or Why Creativity is Important

This section introduces psychological and pedagogical research, such as the five-factor personality model and competency clusters including creativity. Related educational research in STEM disciplines reveals the influence of creativity on students' problem solving. Contrary to these studies, curricular recommendations and practices in computing lack the explicit notion of creativity, which is outlined next.

A. Psychological and Pedagogical Research

Creativity is related to "openness to experience" as a dimension of the so-called Big-Five or five-factor personality model [8], [9] that aligns personality traits along five dimensions. According to the American Psychology Association's Dictionary of Psychology, openness to experience "refers to individual differences in the tendency to be open to new aesthetic, cultural, or intellectual experiences." [12] McCrae and Costa [9] add "fantasy, feelings, actions, ideas, values" to that definition, thereby relating to a new dimension.

Two decades ago, L. Dee Fink developed the significant learning model [13] to broaden Bloom's cognitive domain model and attribute learning to the whole person. As part of the *Application* dimension, Fink's model includes "Critical, creative and practical thinking". This way, he stresses the importance of learners' engagement in various kinds of thinking, not just one, which allows learning to become useful [13].

In the Education for Life and Work report, the National Research Council aligns recent competency models, reports and personality factors to create clusters of closely related competencies resulting in the (1) cognitive, (2) intrapersonal, and (3) interpersonal competence domain [14]. *Creativity* is one of the three clusters within the cognitive domain of competence. It is associated with innovation, complex problem solving skills, generating ideas, and general retrieval abilities [14]. "Intellectual openness" in terms of artistic and cultural appreciation, intellectual interest and curiosity is yet another component of the intrapersonal domain that relates to creativity, as it is associated with openness as a personality factor [14]. In psychology, openness is thus highly associated with creative potential [15], [16].

Statistical studies, as well as formal, controlled studies support the influence of the arts and crafts on scientific innovation in STEM, independent of students' IQ or giftedness. Stimulating scientific creativity through visual thinking [3], [17], drawing [1], painting and sculpturing [4], or auditory training [2] can help STEM students acquire new problem solving strategies and succeed. In the context of visual diagnostics, for example, formal art observation training is applied to improve medical students' skills [18].

B. Curricular Recommendations and Practices in Computing

The analysis of current curricula reports in computing reveals an indecisive level of acknowledgement towards the importance of creativity. Even though the CC2020 includes the knowledge component "design" in the user experience context [10, p. 49], it merely references the "inventive" disposition [10, p. 51], and elaborates it as exploratory, or looking beyond simple solutions. Similarly, the IT2017 [11] mentions the promotion of creativity as one of the principles for curriculum design, but creativity is not issued as learning objective.

A recent study of normative practices reflects the lack of explicit acknowledgement of creativity related learning objectives in engineering curricula [19]. The document analysis of 1109 compulsory course outlines from 42 degree programs shows that only two percent of compulsory courses include goals relating to creativity. A similar study was conducted in the context of computer science curricula [20]. The qualitative content analysis of 126 compulsory introductory programming modules did not identify any learning objective that addresses creativity, neither explicit nor implicit, although educators from the same institutions identified creativity as part of programming competency [21].

Educational practice and research indicates a greater focus on the design of creativity support tools and methods to assist creative people [22], [23]. Despite this dominating relationship to "traditional" design professions, recent research in computing addresses drivers for creativity, such as positive feedback and emotions [24], using robots in programming education [25], visual programming environments such as Scratch [26], or audio programming via EarSketch [27]. Other studies aim at measuring creativity in the context of game design [28], or via system log files of the online programming environment Kodetu [29]. However, a recent systematic literature review on how educators teach creativity in computing stresses the absence of cognitive psychology as basis for the development of pedagogical interventions [30].

III. Desiderata and Research Question

Various studies in the STEM context imply an effect of the arts and crafts on student success. Despite the implications of these studies, they hardly relate to creativity as cognitive competency, disposition or the underlying theory of constructivist learning. This desideratum is reflected in curricular recommendations [10] and actual curricula [19], [20] which do not explicitly aim at creativity. In turn, creativity is considered one of the components of programming competency [20], [21]. Developing algorithmic solutions and writing program code itself inherently constitute constructive learning activities requiring synthesis and creativity. Cognitive psychology theory, however, is ignored as noted in a recent literature review [30]. Assuming that constructivist learning theories and their respective instructional methods can provide a path towards fostering creative problem solving, the research question is as follows:

RQ What are constructivist learning theories' implications in terms of instructional methods to foster creative problem solving in introductory programming?

It is the goal to utilize constructivist theories as a framework for creative problem solving and learning, as *any* construction of meaning requires creativity, and the theories inherently offer an inventory of pedagogical interventions for educators. The author thus identifies the instructional methods for the context of computing to help facilitate students' creative problem solving in programming tasks. As a next step of this work-in-progress, the pedagogical interventions will be applied and evaluated in first-year programming courses with regard to their effectiveness on creativity indicators.

IV. Constructivist Leorning Theories

This paper is based upon cognitive theory and discourse that reflects key constructivist notions on learning and thus the connection of things. For brevity, the author reviews the main points of each theory and identifies their inherent implications on pedagogical practice. The resulting summary of pedagogical interventions is adapted to the context of programming education.

A. Constructivism

There is no constructivist theory per se, it is rather the sum of ideas on learning via the personal construction (or creation) of meaning and corresponding instruction [31]: "There are many ways to structure the world and there are many meanings or perspectives for any event or concept. Thus, there is not a correct meaning that we are striving for." [32] Learning is perceived as active, subjective process that highly depends on individual interpretations and prior experiences. Discussions are a crucial element of constructivist learning and real world problem solving, as they foster learners' awareness and reflection of different perspectives [31]. Well-known representatives comprise J. Piaget, L. S. Vygotskiy, J. S. Bruner, J. Dewey, E. von Glasersfeld, H. Maturana, F. Varela, and D. Merrill. The more radical constructivist theories, however, will not be analyzed due to their neglect of any objective reality.

B. Review of Theories and Implications for Education

1) Jean Piaget: The developmental psychologist **Piaget** is mostly known for his cognitive developmental stage model based on the "Méthode Clinique" [33]. According to Piaget, children learn in four phases via the accomodation and assimilation of new information into schemata in order to adapt to new experiences, whereas schemata describe activities and actions. Assimilation is defined as a reaction based on existing schemata, whereas accomodation describes the change of previously constructed schemata. The four stages of cognitive development are: sensorimotor stage, preoperational stage, concrete operational stage and the formal operational stage. Equilibration is the ongoing tendency of balancing the transformation of mental structures through assimilation and accomodation in all stages.

Likewise, adult learning is the result of interaction with one's environment and the active construction of meaning by the subject. Learning can also take place via social interaction, play, imitation and the corresponding cognitive processes [34]–[37]. "Play is in reality one of the aspects of any activity [...] or one particular type of activity among others." [34] Piaget's theory greatly impacted formal education due to its consistent and complex portray of cognitive processes and their stages. Accordingly, the *creation* of new schemata and building new connections can be fostered via:

- gradually increasing the complexity of learning processes and tasks in alignment with equilibration,
- active learning and experience,
- social interaction among learners and between learners and educator,
- playing games as one type of activity,
- critical thinking and (self-)reflection [38].

2) Lew Semjonowitsch Vygotsky: In the 1940s, the psychologist **Vygotsky** constructed the three stages of cognitive development in terms of language (social speech, egocentric speech and inner speech). In his most famous work "Thought and language", he constructs the utilization of language's social functions by means of social interaction [39]. Vygotsky distinguishes elementary and higher mental functions, whereas the latter comprise cognition and problem solving, and they are developed through the interaction with culture and society. According to Vygotsky, this is the reason why culture determines how success is defined, what is learned, and which adaptions are required from an individual to meet society's expectations. In turn, culture determines our language: "All consciousness is connected with the development of the word" and "the word is a direct expression of the historical nature of human consciousness." [40, p. 271] Vygotsky's theory on the cognitive development and the socio-cultural construction of meaning has several implications for education, e.g., via:

- providing solvable, but challenging tasks,
- scaffolding and student support in form of narratives, demonstrations, feedback, asking questions, etc.,
- social interaction between educators and learners.

3) Jerome Seymour Bruner: The constructivist learning theory by **Bruner** [41] focuses on the human brain's ability to draw connections and develop new, creative solutions to problems. Creativity is, again, inherent. The underlying cognitive concept are so-called mental modes of representations which categorize sensory impressions in infant development into enactive representation (based on action), iconic representation (based on images), and symbolic representation (based on language) [42]. According to Bruner, the development of categories with attributes constitutes the basis for any interaction with the environment and the construction of concepts. A concept is thus "the network of inferences that are or may be set into play by an act of categorization." [43, p. 244]

Based on existing knowledge and experiences, learners select or transform information, construct hypotheses and test them to eventually develop mental models, organize their knowledge and derive meaning [42], [44]. In more recent works, Bruner reflects on the importance of culture for mental activities, as "culture shapes the mind." [45] Recommendations for instructional designs that foster the creation and understanding of a concept include:

- self-guided, exploratory learning to discover concepts, extrapolate, and discover new resources for learning,
- spiral organization of instruction/curricula to repeat core concepts during formal educational programs,
- structuring instruction based on learners' experiences, willingness and readiness to learn [44]–[46].

4) John Dewey: The integration of elements into an interactive whole is one aspect of creativity and polymathic learning noticed by successful STEM professionals, such as Fields Medalist Maryam Mirzakhani [47]. Philosopher and psychologist **Dewey** is assumed to be one of the first to recognize creative people's tendency to create such links [48]. He is adamant in his believe that "art is in the lead in what constitutes new vision." [49] According to Dewey, learners' imagination and "integrated activity sets" [49] can be fostered via pedagogical practice, such as:

- relating to learners' prior experiences,
- dedicating time to experimental work,
- students interrogating and expressing their own thoughts and perceptions,
- recognizing that learning is related to the whole person, emotions, desires, perceptions and prior experiences,
- concrete, multi-sensory experiences and aesthetic stimuli,
- authentic tasks and projects that reflect students' world and concerns [50].

C. Recommended Pedagogical Interventions

Even though the reviewed theories reveal different facets of constructivism, they share common elements regarding the creation of new knowledge and solutions, and therefore lead to pedagogical practices educators can implement in their courses. The first recommendation for educators is to offer *collaborative project work* as learning activity. An example is the design and implementation of a simple game (e.g., via Scratch [51]). It is important to gradually increase the complexity of tasks, e.g., over a duration of 6-8 weeks, and to dedicate time to the exploration and reflection of new solutions. Including visual and auditory elements into the game design is encouraged (see [49], [50]). Structured tasks should be provided, and students should be able to choose between alternatives (e.g., whether to develop human characters or animals). Educators may also provide information on additional learning resources beyond the textbook [44]–[46]. As collaboration and exchange between students is crucial [39], teamwork (e.g., in groups of three) is encouraged. Project work can be complemented with other measures implied by constructivist theory, as summarized below:

- *Social interaction and scaffolding*
  - Provide time for feedback, asking questions, and reflecting on current practices and solutions.
  - Engage discussions or short presentations where every student reflects on a contextually unrelated, novel problem and how they solved it.
  - Make it personal: Educators can reflect on their most frequent challenges as a novice programmer and explain their successful problem solving strategies to students.
  - Invite colleagues as guest lecturers to discuss their examples of successful problem solving, and their strategies.
- *Active learning and multi-sensory experiences*
  - Dedicate time for practice and exploratory learning (via riddles, brain teasers or challenging common practices, such as greedy algorithms).
  - Let experts from other disciplines (e.g., physics) explain how they solve a certain programming task. Ask them to record their solution as short video.
  - Recommend selected media channels as alternative learning resources. Watch and reflect on them together.
  - Use exercises from Scratch, Earsketch, Alice, Kodetu and other tools that address students' senses.
- *Gamification*
  - Include moments of surprise, e.g., invite experts for a Q-and-A session or live-coding, or let students suddenly switch teams in collaborative project work.
  - Award prizes, e.g., for creative solutions, or high quality peer-reviews of code. Ask students to vote for a winner.
- *Authentic tasks*
  - Consult with industry partners to identify current and frequent (solvable!) problems. Integrate them into the course, e.g., as project or for extra credit. Reflect on the required strategy and discuss alternatives how to solve the problem.
  - Ask students what they would like to develop, or which problems they would like to solve that can be aligned with the curricula.

Above all, educators need to make time for questions, discussions and focus more on sharing and valuing diverse experiences, e.g., from other disciplines. Further recommended practices go beyond the limits of educators' scope of action, such as the implementation of the spiral curriculum [44] for programming in primary, secondary and/or K-12 education.

D. Discussion and Limitations

The review of cognitive, specifically constructivist learning theories lead to implications for educational practices focusing on critical, creative, innovative problem solving. The pedagogical methods for the context of programming education align well with other recent literature and recommended practices, such as experimental learning, authentic experiences and the prioritization of creativity over content [30].

Even though cognitive psychology certainly contributes to educator's understanding of learning processes, there is no one-to-one correspondence between theory and practice. Fostering creativity goes hand in hand with problem solving, which is perceived as manifestation of *creating* new connections. At the same time, other cognitive competencies from the interpersonal and intrapersonal domain [14] are promoted (e.g., due to social interaction, active learning and experience), thereby relating learning to the whole person as suggested by Fink [13]. Nonetheless, it is crucial to start focusing on and investigating the *creative* aspect of problem solving and how it can be supported early in programming education. Another aspect of selecting pedagogical approaches to foster creativity is its high dependency on other pedagogical variables (e.g., target group, educator, setting, objectives, assessments), so that not every recommended method will be suitable for every course. Without a set of curricular learning objectives related to creativity, it will remain challenging to foster creative solutions in programming and computing in the long run.

As the present work highly relies on learning theories, the weaknesses of the several theories are reflected in this work. Among them is the criticism regarding constructivism itself concerning its neglect of objectivism [31], Piaget's application of the "Méthode Clinique" to a rather small sample size [33], or the lack of assessment methods for Vygotsky's theory. Due to the page limit, the present work also does not relate to an entire course design in terms of constructive alignment [52].

V. Conclusions and Future Work

Since constructivist learning theories provide a theoretical framework for the *creation* of new knowledge and solutions to problems, the authors reviewed the work of Piaget, Vygotsky, Bruner and Dewey with regard to their pedagogical implications on fostering creative problem solving processes. The result is a synthesis of recommendations for programming education that is extracted from the literature. Among these recommendations is collaborative project work, social interaction and scaffolding, active learning and multi-sensory experiences, gamification, as well as authentic tasks. The contribution of this work in progress is thus the review and translation of constructivist learning theories into the context of basic programming in higher education.

Although some of the interventions may seem to support constructivist learning alone, being creative and connecting things is inherent in the construction of *any* new problem solution. For this reason, the alignment of cognitive theories and programming pedagogy is a considerable contribution that constitutes the basis for future empirical research in computing education. As a next step, the identified pedagogical interventions will be applied in an introductory programming course at a university to measure their effects on students' creativity. Educators are encouraged to pursue similar endeavors and evaluate the recommended approaches in the classroom.

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